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Water Resource Management in the Mandara Mountains: Inventory of the Diversion Bays and Impact of Good Practice in Land Use Planning

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Water Resource Management in the Mandara Mountains: Inventory of the Diversion Bays and Impact of Good Practice in Land Use Planning

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Abstract:

This study aims to assess the status of diversion bays in the communes of Bourha, Koza, Mogodé, Mokolo, Mozogo, and Soulédé-Roua, located in the Mandara Mountains. The methodological approach is based on documentary research, interviews, observation, surveys, and the use of attributes and spatial data. The data were collected via Kobo collect tools, processed using Excel, and specialized with Google Earth and QGIS. The results reveal that among the 736 diversion bays studied, 63.3% no longer exist, and only 36.7% are in good condition. Furthermore, 77.8% of the remaining structures are damaged, primarily due to erosion and poor management. Moreover, 33.1% of the Human-Powered Pumps (HPP) used for drinking water supply are non-functional, exacerbating the water crisis in these areas. Despite efforts by local and international stakeholders, the failure of infrastructure has significant socio-economic repercussions, forcing populations to travel long distances to access water, which is often unsafe for consumption. To address these challenges, integrated approaches such as Integrated Water Resource Management (IWRM) and innovative civil engineering and agroecological techniques have been implemented.

Keywords: Water resource management, diversion bays, best practices, Mandara Mountains.

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INTRODUCTION

Water resources are of vital importance to the economic, social, and environmental development of arid and semi-arid zones. In these regions, where rainfall is often unpredictable and insufficient, sustainable water management becomes essential to meet the growing needs of populations. According to the FAO (2021), more than 40% of people in sub-Saharan Africa do not have reliable access to drinking water, a situation exacerbated by galloping population growth and the impact of climate change (Desjeux, 1985).

Water resource management poses real challenges in Morocco, where techniques for collecting surface water, particularly in mountainous and semi-arid areas, bear witness to ancestral know-how for mobilizing and conserving water, through structures such as hill dams, terraces, or basins, deployed throughout the country (Kingdom of Morocco/MINEMEECEE, 2011). Other similar approaches to rainwater management are also being developed in regions of the world with a similar climate, such as Morocco (MINETLE, GIZ, 2019; MINDEFP, 2012; MINEMEE, 2010; MINAPM, 2009).

In countries such as Belgium, Germany, and Sweden, rainwater harvesting for domestic and industrial purposes is commonplace. These nations have introduced national legislation governing the installation of rainwater harvesting systems, backed by incentives to encourage their adoption. Civil society and residents are actively involved in awareness-raising efforts and in implementing projects to collect and reclaim this water (IFAD, 2013; FAO, 2010).

In Cameroon, the Extreme North Region, located in the Sudano-Sahelian zone, is constantly affected by climatic hazards that limit groundwater recharge (Olivier et al., 2000). This situation has a particular impact on local populations, especially those living in rural areas, who are among the most vulnerable. This is the case for the inhabitants of the Mandara Mountains, where the challenges linked to water supply are becoming critical. The mountainous topography of this region, with altitudes sometimes reaching thousands of meters, makes it difficult to drill boreholes or wells due to the rocky nature of the subsoil and the low capacity of aquifers to store water (Damien, 1992).

In villages such as Djingliya Montagne, Tourou, Ziver, Hirché, Soulédé, and Bao, the construction of a series of diversion bays on rivers is an essential alternative to traditional boreholes and wells. These diversion bays raise the level of the water table to effectively supply downstream water infrastructure (PCD Koza, 2020; PCD Mokolo, 2023).

The creation of diversion bays to divert and redistribute water proved essential for local populations, particularly after the major droughts of the 1970s and 1984, which prompted governments to introduce Emergency Village Hydraulics Programs (PUHV) (Josaphat, 1994). However, the situation remains worrying because of the weakening of the water tables, exacerbated by unfavorable climatic conditions. The annual water balance has fallen by 150 mm in less than 25 years, putting increased pressure on water resources in the face of demographic growth.

In the Mandara Mountains, the diversion bays play a crucial role in water management by holding back floods and encouraging infiltration to replenish the water table (Seignobos, 2000). Despite their importance, over 80% of these structures are now out of use by local authorities. The first structures, built between 1984 and 1989 as part of strategic policies such as the *Programme d'Urgence d'Hydraulique*

Villageoise (PURHV) launched in 1982, have almost completely disappeared. Of the ten diversion bays built, only two are still operational or require major rehabilitation (Iyébi-Mandjek, 2000).

This advanced deterioration is exacerbated by the absence of diversion bay management committees and appropriate maintenance systems. Local people, who have little involvement in the upkeep of these infrastructures, are faced with conflicts over access to water, particularly in the dry season, when women and children have to travel long distances to find it (Damien, 1990). In addition, erosion and torrential rains have caused significant damage, leading to the destruction of many diversion bays, a heavy build-up of sediment in reservoirs (Annavaï, 2012), and accelerated degradation of farmland (Seiny, 1995).

The Communes of the Mandara Mountains region are faced with a crying lack of water infrastructure to meet the water needs of their populations. Existing facilities are inadequate, often poorly maintained, and even obsolete. According to data from the Communal Development Plans of six Communes (Bourha, Koza, Mokolo, Mogodé, Mozogo, Soulédé-Roua) in 2024, nearly 46.7% of the Human Powered Pumps (HPP) are out of service. Around 30% of households use unsafe water, and only 28% of residents have access to a source of drinking water. This situation highlights the urgent need for effective management of water resources to meet the growing needs of the local population (Clément and Dulawan, 1985). The lack of diversion bays in the mayos (rivers), coupled with erosion and sediment accumulation, limits the recharge of these aquifers, reducing the effectiveness of existing water infrastructure (Annavaï, 2012).

In addition, the inability of local authorities to generate sufficient tax resources hampers their ability to invest in local or sectorial maintenance systems. Over the last five years (2019-2024), less than 35% of the Communes in River Sanaga have allocated funds to hydraulics, leaving 70% of the infrastructure in poor condition. This also compromises important projects such as the construction of mini-water reservoirs or dams, which are often carried out by development partners, although efforts remain insufficient. Indeed, the Communes give priority to other infrastructure projects such as public works, education, or street lighting, neglecting the reservoirs and thus reinforcing their dependence on state subsidies and NGO support.

The lack of qualified technicians in the region is also a major obstacle to the management and development of water infrastructure. Although training initiatives have been carried out, such as those by Care International (1992), which trained 200 craftsmen between 1978 and 2005, the majority of these are no longer able to practice or pass on their skills (GOIB, 1989). As a result, the Communes find themselves without a skilled workforce to design, build, and maintain these infrastructures, especially as they do not have the resources to organize ongoing training.

Despite playing a central role in the decentralized management of water resources, municipalities face significant obstacles in coordinating with NGOs and other stakeholders, which hampers the effective implementation of development projects. As a result, residents of mountainous regions such as Mokolo, Koza, and Soulédé-Roua are forced to travel long distances to access water, particularly during the dry season from February to June. During this period, wells and Human Powered Pumps (HPP) frequently dry up, forcing residents to turn to natural sources such as mayos (rivers). However, only the wealthiest households can afford to pay for access to water sources (Damien, 1991).

Similar techniques are also used in Cameroon. To meet their water needs and environmental and agricultural challenges, the Communes of the Mandara Mountains are adopting agroecological practices, focusing on the use of waterways and rainwater harvesting. This approach aims to relieve pressure on traditional water resources and exploit new water sources while promoting the socio-economic development of rural areas. At present, the communists apply good agricultural, hydraulic, and ecological practices to ensure sustainable management of water and soil through the diversion bays (PIDACC, 2024).

MATERIALS AND METHODS

Geographical Setting of the Study

The Mandara Mountains stand majestically in the Far North region of Cameroon, extending mainly over the Mayo Méri and Diamaré departments. They lie between latitudes 9°50' N and 11°35' N, and longitudes 13° E and 14°15' E. To the west, they share a border with Nigeria, while to the south, they dominate the Benoué basin. To the north, the Mandara Mountains extend towards Chad, and to the east, they merge into the Diamaré plain. These mountains reach an average altitude of around 900 meters, rising proudly between the Benoué basin and the Chad plain (PDRM, 1996). Their geological origins are linked to a fracture in the earth's bedrock, creating a raised block that stretches from north to south for 150 kilometers, with a width of around 50 kilometers. Mount Oupay, the summit of the Mandara Mountains, reaches an altitude of almost 1,500 meters, while the majority of the massifs are between 1,000 and 1,200 meters above sea level. Whatever the angle of approach, the steep relief rising above the surrounding plains and the extent of the differences in altitude give the Mandara Mountains the appearance of a veritable tropical mountain range (Boulet, 1975). The Mandara Mountains can be divided into three distinct morphological groups: the internal plateaux, such as those of Mokolo and Bourha, the border mountainous reliefs, and the island massifs of the main chain (Figure 1).

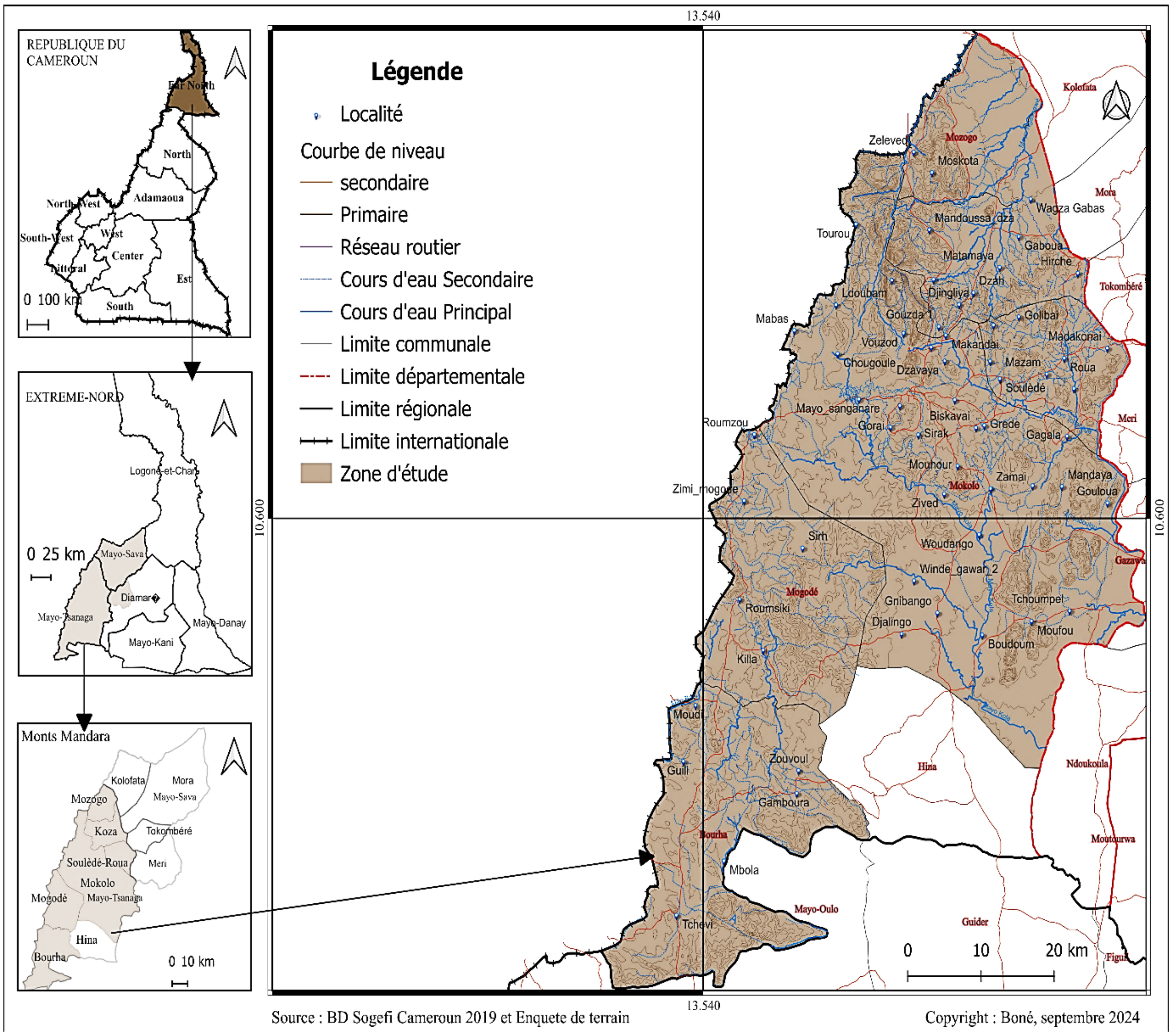


Figure 2. Location of study areas

The Mandara Mountains comprise the Communes of Bourha, Koza, Mogodé, Mokolo, Mozogo, and Soulédé-Roua, covering a large part of the Far North Region. These Communes are ideally suited to the implementation of village water projects such as diversion bays. They were chosen because of the common challenges faced by local authorities when implementing these schemes, highlighting diverse socio-economic and environmental realities.

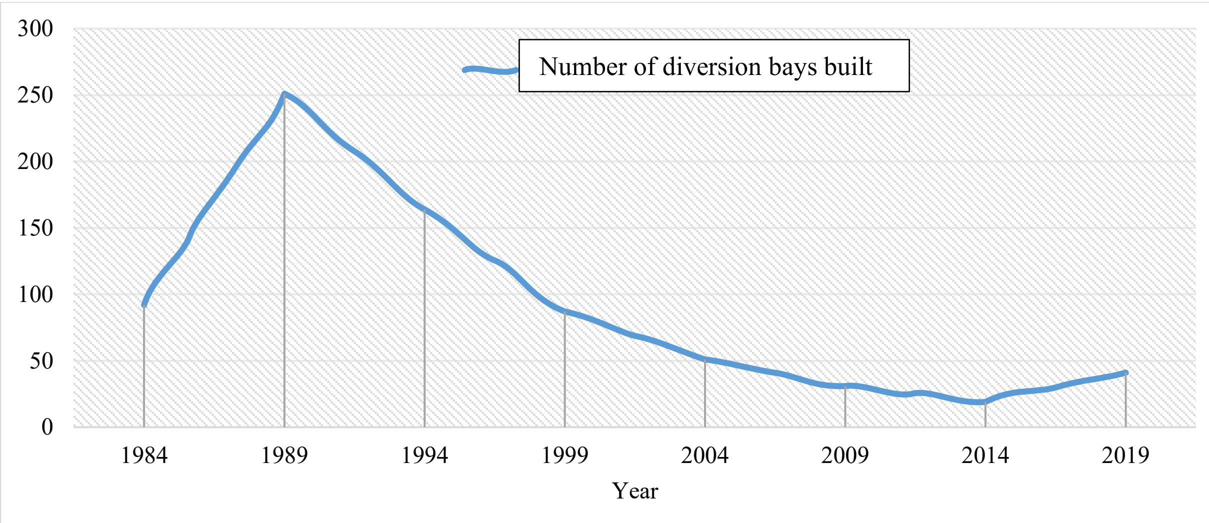
Methods

This study is based on documentary research (archives, reports, articles, dissertations, and theses), direct observation, and the use of geolocation tools (GPS, Kobo Collect). The literature review provided an overview of the challenges associated with access to water, the management of the diversion bays, and the best practices put in place by local populations, confirming the originality of the research. The field survey involved 2,000 households selected based on stratified sampling. Six (6) of the 11 communes in the Mandara Mountains were covered, with the analysis of at least six (6) diversion bays per commune and the participation of 36 elected representatives and technicians. Semi-structured interviews were held with mayors, technicians, heads of sectorial organizations, NGOs, local organizations, and users, supplemented by observations and 24 focus groups. The information gathered made it possible to draw up an inventory of water infrastructure. The household survey and field surveys revealed the difficulties of access to water and mapped existing structures and innovative practices. Google Earth and QGIS software were used to create the maps and specialize the actions undertaken.

RESULTS

Diversion of Bay Development Project in the Mandara Mountains Communities

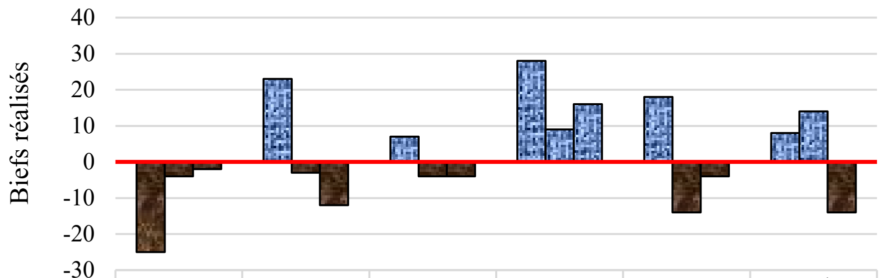
The work carried out to develop the watercourses in the Mandara Mountains highlights the importance of the diversion bays, especially during periods of rain and drought. Even if access to water is not a direct problem, the current infrastructure is not sufficient to ensure that they function properly. These structures are crucial for recharging water tables, controlling floods, and maintaining a healthy environment after the rains. However, the deterioration of the diversion bays, which affects their water retention capacity, has a direct impact on the fall in groundwater levels. Local communities depend mainly on surface and groundwater resources, but there are major disparities between the demand for and supply of diversion bays in the Collectivities of the Mandara Mountains. Despite the favorable context, efforts to develop village hydraulics and improve access to water remain insufficient in these arid regions (Figure 2).



Source: Field surveys, 2024

Figure 2. The trend in the number of diversion bays completed by period (1982-2024)

Figure 2 shows the trend in the number of diversion bays from 1982 to 2024. During the period 1982-1992, progress was minimal. However, significant growth was observed from 1993 to 2003, highlighting the third and fourth periods. Between 2004 and 2014, there was a slight but steady increase, reaching a peak in the fourth period, followed by a slight decline until 2024. The last decade shows stable, albeit less marked, achievements. These fluctuations reflect changes in hydraulic management, available resources, and socio-political contexts, all of which have an impact on the number of diversion bays built in the study areas. The diversity of trends observed highlights the importance of taking several factors into account when analyzing and interpreting these data (Figure 3).



Communes	Bourha	Koza	Mogodé	Mokolo	Mozogo	Soulédé-Roua
Différence 1993-2003 et 1982-1992	-25	23	7	28	18	8
Différence 2004-2014 et 1993-2003	-4	-3	-4	9	-14	14
Différence 2015-2024 et 2004-2014	-2	-12	-4	16	-4	-14

Source: Field surveys, 2024

Figure 3: Comparative evolution of diversion bays built in the Communes between 1982 and 2024

This illustration shows the evolution of diversion bay construction in six Communes over three successive periods: 1982-1992, 1993-2003, 2004-2014, and 2015-2024. Mokolo and Koza show a significant increase at the beginning, while Bourha shows a significant decrease. Subsequent periods show a general downward trend, particularly marked in Mozogo and Souléde-Roua. These results indicate the challenges of planning, funding, and local priorities for water infrastructure management, with disparities between Communes.

The mapping of the diversion bays shows that Koza and Mokolo have more infrastructure than other areas (Figure 4).

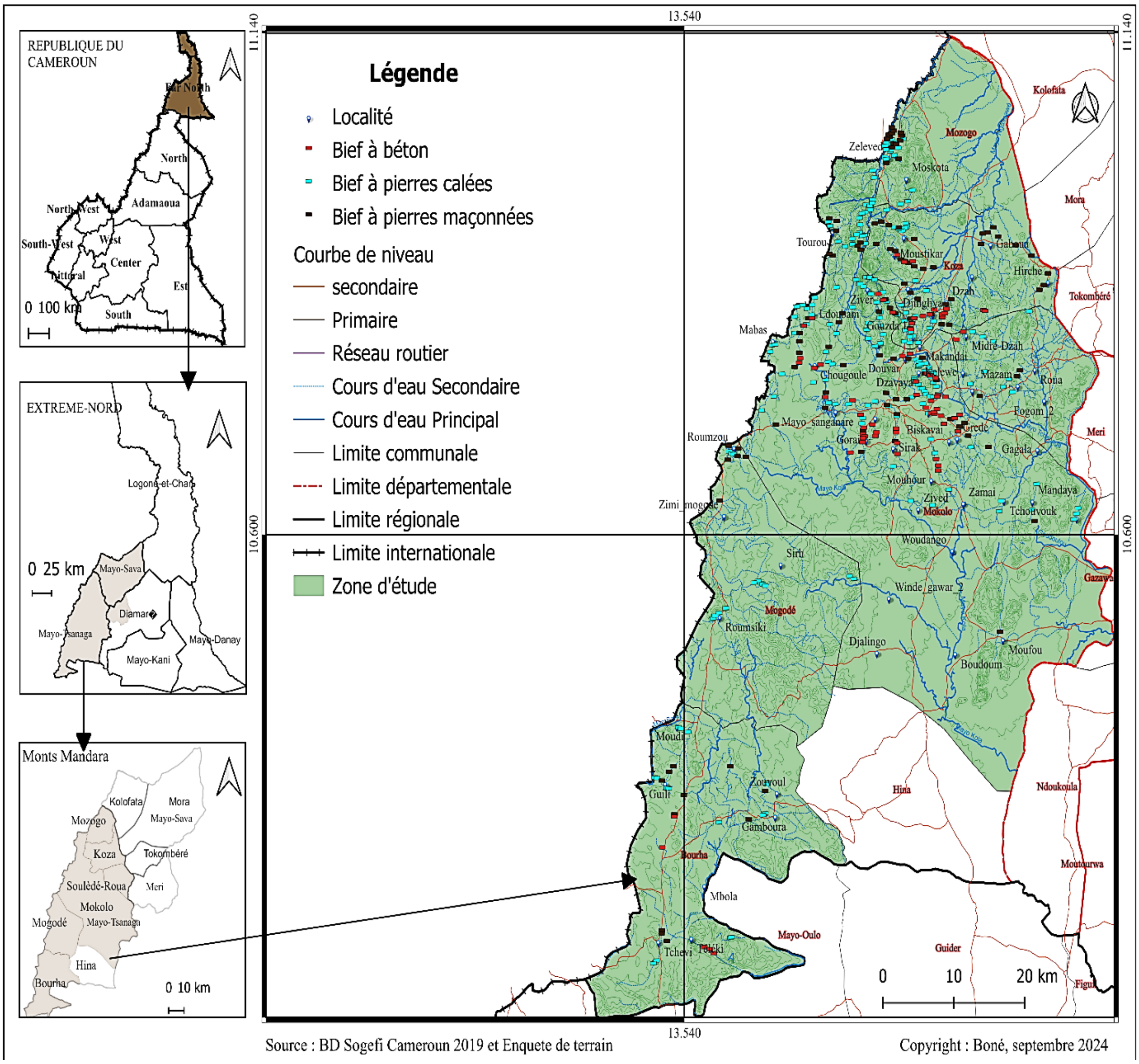
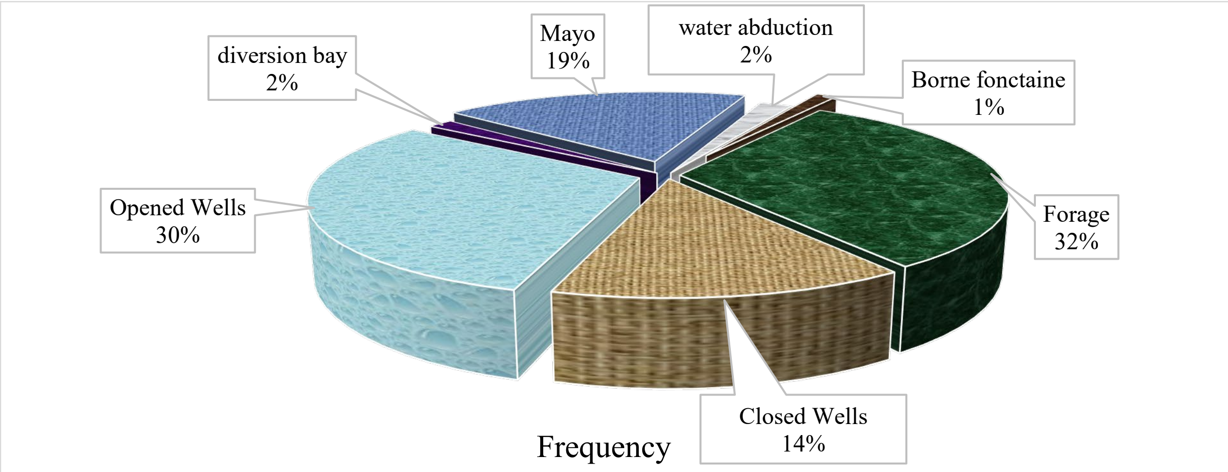


Figure 4. Spatial distribution of diversion bays in the study areas

Figure 4 shows the distribution of the different types of diversion bays (concrete, masonry, wedged stone) built in the Monts Mandara. It shows an uneven distribution, with a high concentration in the Communes of Mokolo and Koza, while other Communes such as Bourha, Mogodé, and Mozogo have practically none. This highlights the wide disparities in access to this water infrastructure, which is crucial to the villages (Figure 5).

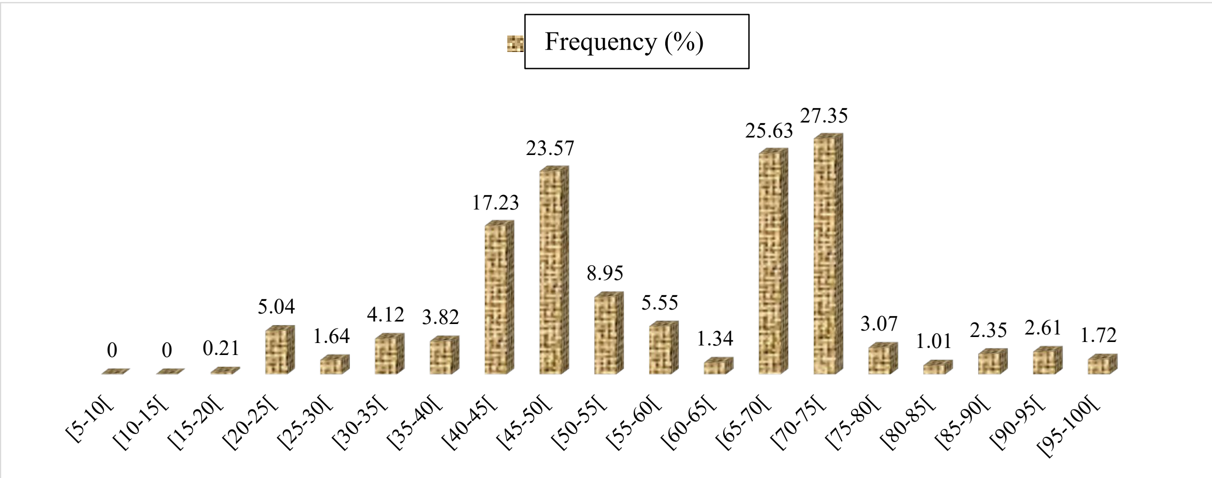


Source: Field surveys, 2024

Figure 3. Water Supply Systems

The graph highlights the diversity of water supply systems in the Mandara Mountains. It shows that boreholes dominate with 32.2%, followed by open wells (30%) and mayos (19%). Other sources, such as closed wells, piped water supplies, standpipes, and diversion bays, are much less well represented, reflecting heavy reliance on rudimentary infrastructure.

This inequality in available sources has a direct impact on daily water consumption per household, which remains insufficient to cover the needs of local populations (Figure 6).



Source: Field surveys, 2024

Figure 4. Distribution of daily water consumption per household in the study areas

Daily household water consumption shows peaks between 65-70% and 70-75%. Low ranges, such as 5-10% and 10-15%, are absent, while intermediate ranges, such as 20-25% and 40-45%, account for 5.04% and 17.23% respectively. On average, each household uses around three 25-litre cans per day, corresponding to an estimated overall demand of 646,603 m³ per day.

The diversion bays, whether mini-dams made of wedged stones, masonry, or concrete, located in the mayos, although modest in size, play a fundamental role. They hold back a significant proportion of floodwater (34.14%), helping to reduce the risk of downstream flooding (17.33%), slowing the flow of watercourses (14.21%) and protecting riverbanks from erosion (10.31%). In addition, these infrastructures support the development of gardening activities (16.73%), create essential habitats for flora and fauna (4.21%) and contribute to the enhancement of local heritage (3.10%) (Plate 1).

A. 13,82222N 10,79081E ©Boné, May

B. 13,82222N 10,79081E ©Boné, May 2020

Photographic plate 1. Rainwater conservation through the diversion bay during the dry season at Woudahaï

The conservation of rainwater through the diversion bays during the dry season illustrates the essential role of these structures in the management of water resources. They enable rainwater to be stored to meet needs during periods of drought. This technique helps to maintain soil moisture, encourages market gardening, livestock watering, washing and bathing, and contributes to the preservation of local ecosystems. It also highlights the importance of these infrastructures in adapting to climate change and the variability of rainfall in areas facing water shortages.

Despite their many environmental and socio-economic benefits, the current state of the diversion bays remains a cause for concern, requiring action to guarantee their effectiveness and long-term survival.

Status of the diversion bay

Mapping of the diversion bays reveals a high level of deterioration due to various factors, such as climate, poor design, lack of maintenance, and the fiscal and technical weaknesses of the Communes.

A very high rate of deterioration

The mapping of the diversion bays shows a large number in a very poor state of repair or even gone, resulting in a significant loss (Table I).

Table I. Status of completed, disappeared, and existing diversion bays by type and condition (2024)

Completed	Disappeared	Existing	Masonry Stone Reach (MSR)	Wedged Stone Reach (KSR)	Statu			
					MSR		KSR	
					Good	Poor	Good	Poor
736	466	270	120	150	48	72	12	138

Source: Field surveys, 2024

The table provides an overview of completed, disappeared, and existing diversion bays, classifying them by type (MSR or KSR) and current condition (good or poor). Of a total of 736 diversion bays initially built, 466 have disappeared, leaving 270 still in place, representing a loss of almost 37%. Of the remaining structures, masonry diversion bays (Biefs en Pierres Maçonnées - BPM) dominate, with 120 in good condition and 150 in need of rehabilitation. Although fewer in number, the calcareous stone forebays (Briefs en Pierres Calées - BPC) are in good condition (48), poor condition (72) and have recently been identified as being in critical condition (12) (Figure 7).

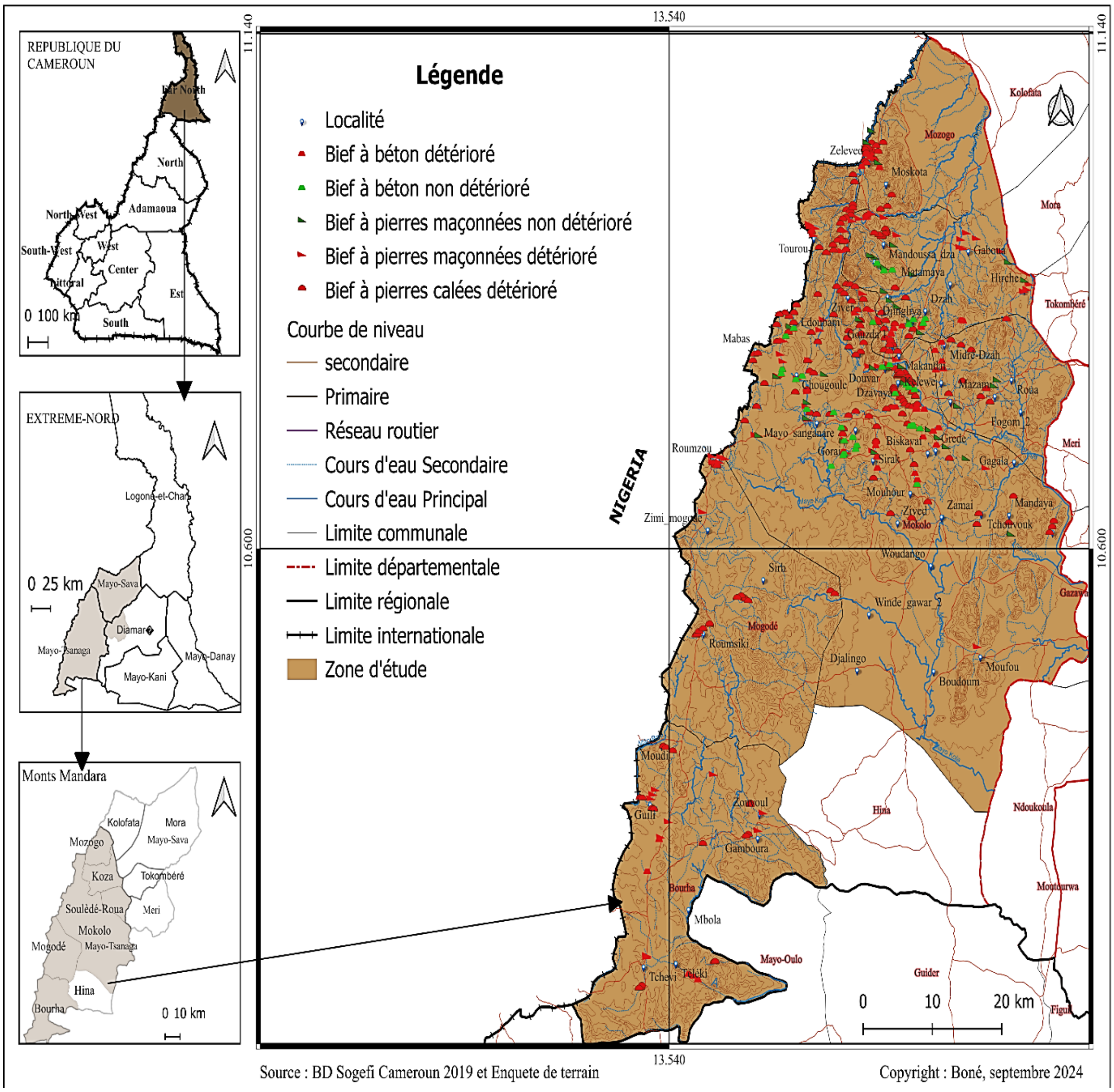


Figure 5. Spatial distribution of the condition of the diversion bays

The map analysis of the condition of the diversion bays shows an alarming deterioration, particularly marked in the areas studied. The majority of the masonry (BPM) and wedged stone (BPC) diversion bays are in a deteriorated state, in all the Communes concerned, which indicates a widespread problem. On the other hand, although there are only a few Concrete Bays (BB), some structures are still in good condition in certain localities.

These findings, based on recent data, underline the urgent need for action to rehabilitate and maintain this vital infrastructure. Moreover, the forms of deterioration vary from one structure to another (Plate 2).

A) Overturning of a masonry forebay at Dzah (Koza)

B) Scouring of a concrete forebay at Dzah (Koza)

C) Erosion of the protective wings of a masonry forebay at Mandaka (Mokolo)

D) Erosion of the retaining wall of a masonry forebay at Mandaka (Mokolo)

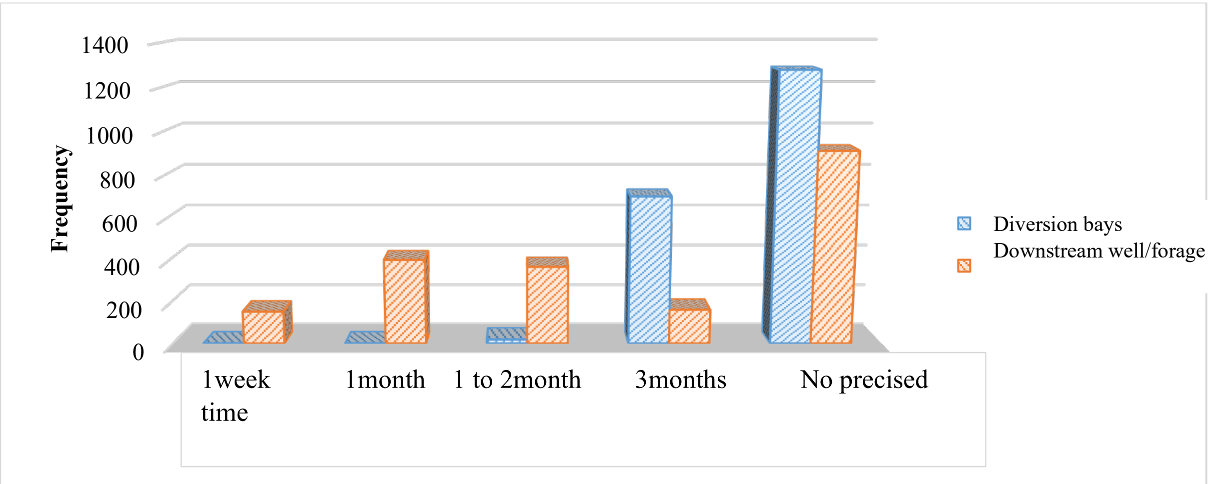
Photographic plate 2. Types of deterioration of the Koza and Mokolo diversion bays

The types of deterioration of the structures vary to some extent. Some are damaged by overturning, subsidence, or lateral displacement. Other factors, such as erosion of the wings of the structures or scouring of the protection zones under the effect of water, also contribute to their deterioration. These processes impair their ability to hold back water effectively, eventually leading to the collapse of the infrastructures concerned.

An inadequate system management

The problems associated with diversion bay management are frequently identified and analyzed. A majority of 94.2% of households attributed the inefficiency or absence of a system for monitoring and managing structures to the technical and organizational limitations of the beneficiaries or users. Similarly, the lack of funding and municipal support is a major challenge, cited by 83.1% of respondents. The issues of coordination and consultation between the players involved were also significant, at 42.1%. In comparison, economic and property pressures, as well as conflicts of interest or jurisdiction, were seen as less influential, with respective rates of 18.9% and 22.7%.

The lack of River Reach Management Committees (COGEB) after the construction of the structures is a major obstacle to their maintenance, sustainability, and effectiveness. This dysfunction has a direct impact on the time required to rehabilitate rural hydraulic infrastructure in the areas concerned (Figure 8).



Source: Field surveys, 2024

Figure 6. Time taken to bring diversion bays and downstream boreholes/wells back into service, by period

The figure shows the time taken to bring diversion bays and downstream boreholes/wells back into service, by period. The diversion bays are particularly slow to respond, with none being restored in less than three months, reflecting significant organizational shortcomings. On the other hand, boreholes and wells are characterized by a faster return to service, generally in less than a week. However, despite this relative performance, the time taken to restore boreholes and wells remains much shorter than that for diversion bays.

Inexistence of diversion bay projects investment plans

Like DMCs, diversion bays play a central role in rural water resource management, fulfilling a variety of functions despite budgetary limitations. However, the construction of this essential infrastructure seems to be relegated to the back burner by the Communes, as in the municipalities of Koza and Mokolo, where no works were recorded between 2016 and 2019. The explanations put forward, often of a financial nature, although they may seem justified, raise questions about the choice of priorities and the absence of a long-term strategy for local development (Table II).

Table II. Distribution of local authority properties and sectors of intervention

Sector	%	Frequency
Education	34.6	410
Hydraulics	25.3	301
Health	10.2	121
Road	29.9	356

Source: Field surveys, 2024

Table II highlights the priority areas of intervention for local authorities. Education comes first with 34.6%, reflecting the importance attached to the training and development of citizens. Road infrastructure follows with 29.9%, underlining the pressing need for transport. Water came third with 25.3%, highlighting the importance of access to drinking water. Finally, health, although essential, is relegated to last place with just 10.2%. These priorities reflect the main challenges facing these communities while revealing gaps in the balance between the different sectors.

This situation calls into question the sustainable and efficient management of natural resources by the Communes, particularly in a context where the impacts of climate change are intensifying and where water has become a critical and strategic resource in recent decades.

Degradation factors and impacts

Dans les zones d’étude, deux (2) principales catégories de facteurs contribuent à la dégradation des biefs, notamment : les facteurs naturels, comprenant les aspects hydrauliques et biologiques, et les facteurs anthropiques, qui incluent les dimensions géométriques, géotechniques et sociales. Ces influences combinées engendrent des répercussions notables, tant sur l’environnement que sur les conditions socioéconomiques des populations concernées. In the study areas, two (2) main categories of factors contribute to the degradation of the diversion bays: natural factors, including hydraulic and biological aspects, and anthropogenic factors, which include geometric, geotechnical and social dimensions. These combined influences have significant repercussions, both on the environment and on the socio-economic conditions of the populations concerned.

Deterioration factors

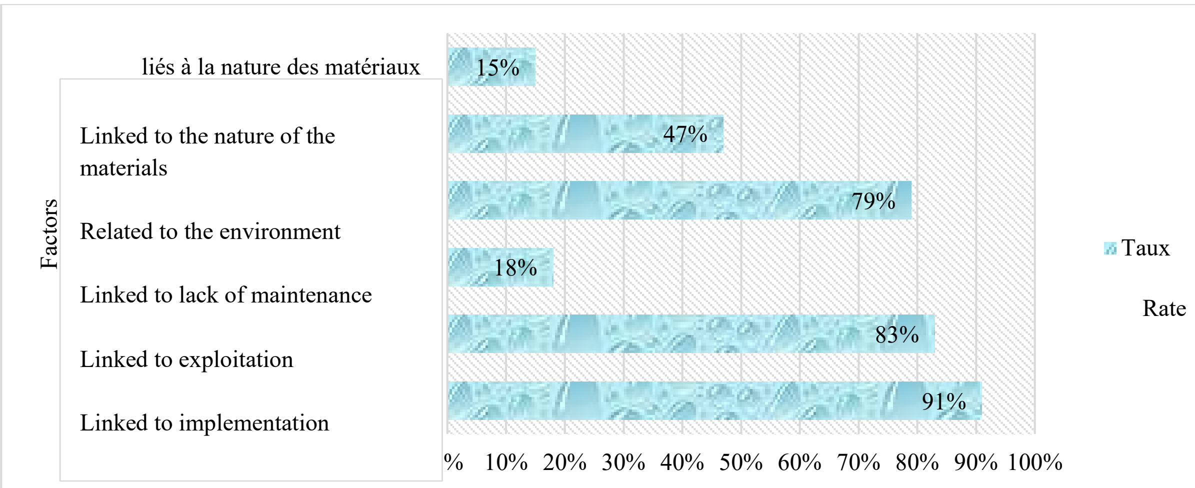
The diversion bays face many threats that accelerate their deterioration, particularly as a result of biological and human factors. On the biological side, the proximity of woody plants is a major problem for the long-term survival of these structures. Local plant species, such as "Brom, M'bouv, Hawan, Jagola, Waɗar, ..." in the Mafa language, are gradually invading these structures, sometimes transforming the diversion bays into dense aquatic jungles. This uncontrolled proliferation of vegetation is causing considerable concern among local communities, who see this colonisation as a serious threat to the preservation of their essential water resources (Photographic Plate 3).

Photographic plate 3. Diversion bays under the influence of arborescent vegetation

The plate shows how the structures are invaded by plant species, particularly at the reservoir and spillway. This plant proliferation has negative consequences, as the roots of the plants, present in and around the structure, cause damage to the materials of the structure.

From a human point of view, various factors contribute to the deterioration of the diversion bays. These include errors in the design and construction of structures, inadequate maintenance, and difficulties relating to operation, the environment and the quality of the materials used (Figure 9).

Figure 9: Factors leading to deterioration of the diversion bays



Source: Field surveys, 2024

The data show that design errors (91%) are among the main causes of deterioration of the diversion bays in the Mandara Mountains areas. This was followed by problems with implementation (82%) and maintenance (79%). Environmental factors also play a role, accounting for 48% of the causes of deterioration. Without a serious review of the design and improved management of hydraulic infrastructures, these References will continue to suffer significant damage.

Social and institutional factors also contribute to the deterioration of the diversion bays. Socially, there is a clear lack of local responsibility. Local communities, who are the main beneficiaries, do not take part in the management of their infrastructures, such as upkeep or maintenance, which indirectly encourages their deterioration. From an institutional point of view, these works suffer from the inefficiency and neglect of the institutions responsible for managing water resources, such as the Ministry of Agriculture and Rural Development (MINADER), which lacks technical and financial resources. In addition, local development organisations such as the *Gestion des Organisations et des Infrastructures des Biefs* (GOIB) and the *Mission de Développement Intégré des Monts Mandara* (MIDIMA) have ceased their activities for lack of funding, leaving communities without support for their water projects. At local government level, the Communes give priority to short-term projects such as education and road infrastructure, to the detriment of long-term management of the diversion bays and water resources. This situation is exacerbated by a lack of will on the part of the mayors and a lack of coordination between the local authorities and the NGOs, which leads to redundant projects and insufficient coverage of needs, thus reducing the impact of the interventions. (Table III).

Tableau II. Main factors linked to fiscal weakening in the study Communes

Identified Problems	Frequency	%
Insufficient tax revenue	36	24,32
Delays in State transfers	26	17,57
Lack of qualified technicians	30	20,27
Lack of adequate hydraulic equipment	24	16,22
Deficit in community investment	32	21,62

Source: Field surveys, 2024

Table III shows the main obstacles to taxation in the Communes analyzed. Insufficient tax revenue tops the list, affecting 24.32% of the Communes, and underlines the over-reliance on tax resources for local financing. In addition, delays in transfers from the State (17.57%) and the lack of investment by the communities themselves (21.62%) point to a lack of funding and commitment from the State to Local Authorities. Furthermore, the absence of qualified technicians (20.27%) and the lack of appropriate hydraulic equipment (16.22%) reduce the effectiveness of the Communes in managing their resources, highlighting a lack of staff and material resources. Taken together, these factors generate a climate that is unfavorable to the fiscal and operational capacity of the Communes, threatening their smooth operation.

Consequences de of the deterioration of the diversion bays

La dégradation des biefs a un impact majeur sur l'équilibre des écosystèmes aquatiques ainsi que sur les activités humaines qui en dépendent. The deterioration of the diversion bays has a major impact on the balance of aquatic ecosystems and on the human activities that depend on them

Consequences of the aquatic ecosystem

Degradation of the diversion bays leads to a significant reduction in aquatic habitats (82.9%), which has a negative impact on ecosystems by reducing watercourses and rapidly drying out wetlands, making the environment less suitable for aquatic fauna and flora. In addition, 70.4% of participants reported a decline in biodiversity, creating a worrying ecological imbalance. Hawama, a fisherman from Woudahaï, expressed his concerns about the disappearance of aquatic life, particularly fish, macro-invertebrates and certain plants. In addition, the degradation of the diversion bays is disrupting hydrological cycles (93.1%), speeding up the drying up of water bodies during the dry season, as these infrastructures no longer effectively regulate the flow of water.

Although 79.7% of residents have access to water throughout the day, only 10% of them manage to obtain a sufficient quantity to meet their needs. These difficulties in accessing water remain a major problem in the municipalities studied. Table IV provides an overview of the time required to access water in these areas.

Table IV. Rate of time taken to access water by main source of supply in the study areas

Average time on foot to fetch water	On site	Less than 15 min	15 to 30 min	More than 30 min
%	2,1	11,7	35	51,2
Frequency	42	234	700	1024

Source: Field surveys, 2024

Table IV shows that 51.2% of households spend more than 30 minutes fetching water, which highlights the difficulties in accessing this resource. Only 2.1% of households have immediate access, while 35% take between 15 and 30 minutes to collect water. In areas such as Koza and Mokolo, 78.6% of households have to make long journeys to access water. In addition, 75% of households consider their water source to be of poor quality, 91% deplore the lack of water points, and 59% criticise the state of the water. These concerns demonstrate the urgent need to implement solutions to improve water supply and meet people's needs.

Consequences on human activities

The degradation of the diversion bays has direct consequences for the local communities that depend on this infrastructure for various economic and subsistence activities. When the diversion bays are in poor condition, they are no longer able to irrigate farmland, which, according to household surveys, contributes to 72.3% of agricultural disruption, leading to lower yields and exacerbating food insecurity. In addition, the reduction in aquatic habitats resulting from the deterioration of the diversion bays is causing a shortage of fish, leading to the disappearance of fishing (61.4%), which is essential for many families, both for their food and their income. The deterioration of the diversion bays is also affecting access to drinking water (94.8%), and the shortage of this resource is causing conflicts over water use (97.3%), creating social tensions between farmers, livestock breeders and households. A total of 97 conflicts were reported in the Koza (12), Mokolo (27) and Soulédé-Roua (58) zones between 2018 and 2024. This situation particularly affects agroforesters, farmers, market gardeners and livestock breeders (Table V).

Table V. Agricultural and rural populations vulnerable to the effects of the deterioration of the diversion bays

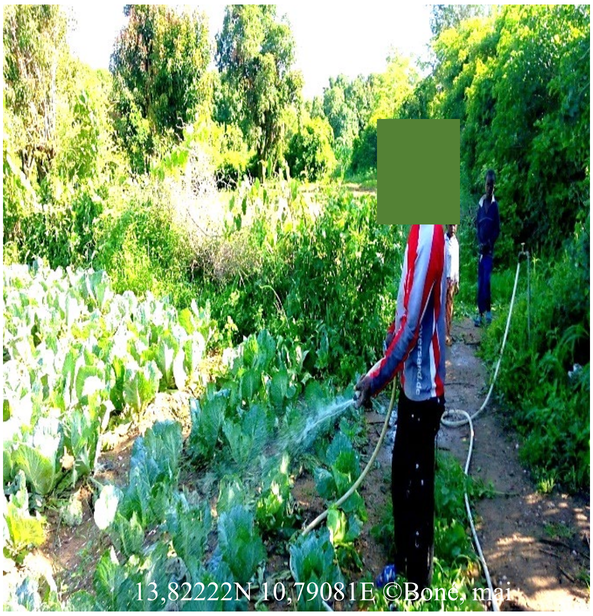
	%	Frequency
Gardener	85,3	1706
Shop-owner	3,4	68
Stockbreeder	73,8	1476
Butcher	4,1	82
Civil servant	2,8	56
Farmer	93,2	1864

Source: Field surveys, 2024

Table V reveals the increased vulnerability of rural and agricultural populations to the deterioration of water infrastructure, highlighting their direct dependence on the diversion bays for their economic activities. The populations most affected by this situation are mainly farmers, with 93.2% of households affected (1,864), and followed by gardeners (85.3%) and livestock farmers (73.8%).

By contrast, shopkeepers, civil servants and butchers were less affected, with rates of 3.4% (68), 2.8% (56) and 4.1% (82) respectively.

From an economic point of view, these annual losses are considerable for farmers, particularly because of the damage to crops and the costs associated with using tap water as an alternative for irrigating their plants (Photo 4).



A) Use of tap water by market gardeners

B) Plants destroyed by chemicals from tap water

Photographic plate 4. Destruction of plants by chemicals from tap water (Camwater) in Mandaka

This plate highlights the environmental concerns in Mandaka linked to the use of tap water for crop irrigation. The chemical residues left behind by Camwater's water treatment disrupt local ecosystems, degrade soil quality and harm plant growth. It is therefore essential to find alternatives to protect the environment and the health of crops.

Overall socio-environmental consequences

The degradation of the diversion bays is part of a wider context of desertification and land deterioration in the Mandara Mountains. This phenomenon is intensified by unsustainable agricultural practices, the effects of climate change and growing demographic pressure (Photo 5).

A) Destruction of land in Midré (Souledé-Roua)

B) Destruction of riverbanks in Mandaka (Mandaka)

Planche photographique 5. Destruction of riverbanks and plots of land in the study areas

These images reveal the destructive impact of the deterioration of the diversion bays and farming activities, which are weakening the riverbank ecosystems. The deterioration of riverbanks not only reduces biodiversity, but also intensifies erosion. The same applies to terraces.

The data reveals the growing vulnerability of local communities to the effects of climate change (62%) and the worsening of poverty due to the loss of their means of subsistence (93.7%). This is leading to environmental migration to more fertile land, increasing pressures in other regions (96.9%). This migration occurs both nationally, with people moving from the mountains to the foothills or plains, and internationally, with mountain dwellers seeking new arable land in the northern plains.

Actors and actions in the diversion bays projects

The mapping of the actors involved in building the diversion bays reveals a variety of stakeholders, both internal and external, working on development projects focusing on access to water. Internal stakeholders include MINADER/Génie Rural, communes, local populations represented by their community organisations or GOIB, and Village Development Committees (CODEVI) such as CODEVIGO, CODEVIMA, CODEVIMO, CODEDJIVE, among others. External stakeholders include NGOs such as WWF/CAPROD-CAM and Care International, churches (notably UEBC), and development partners such as CDD and CRB (Figure 10).

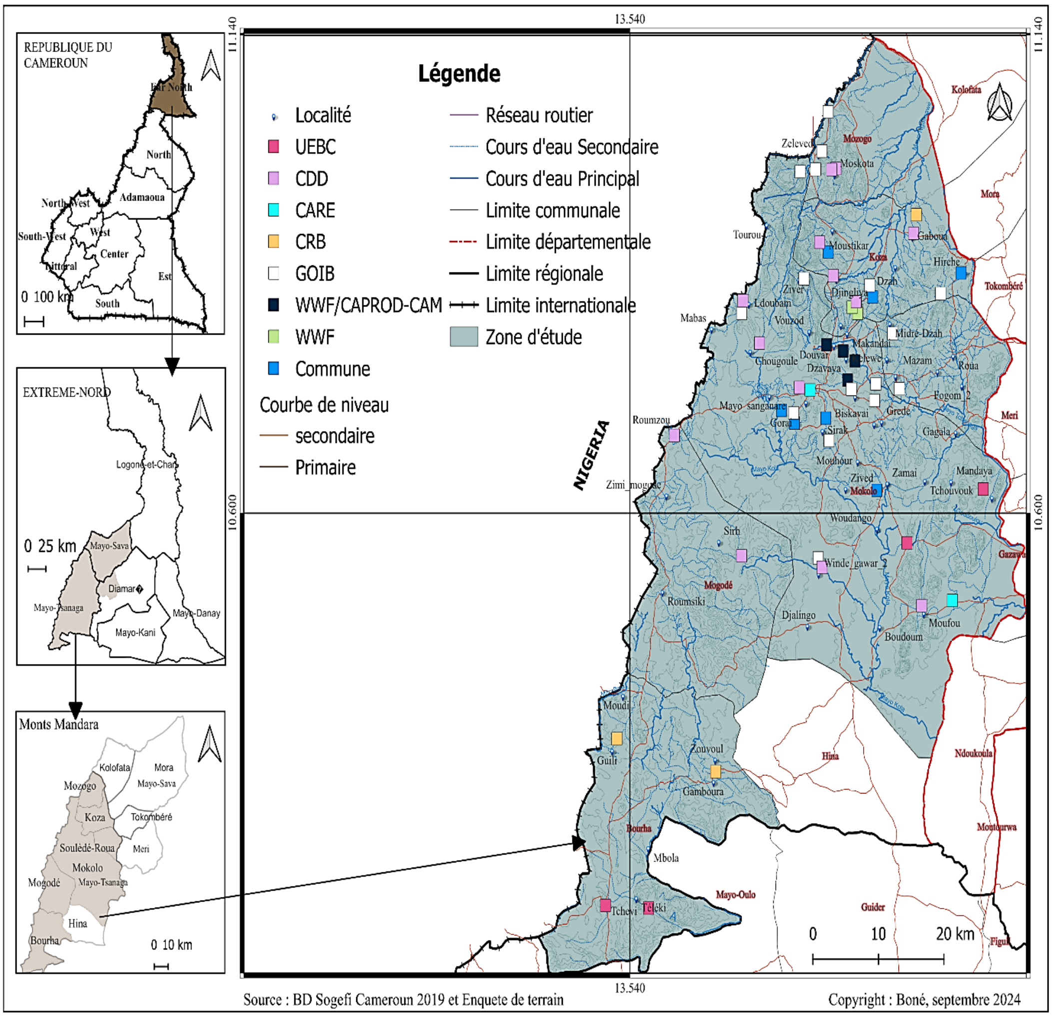


Figure 10. Map of stakeholders in the creation of the diversion bays

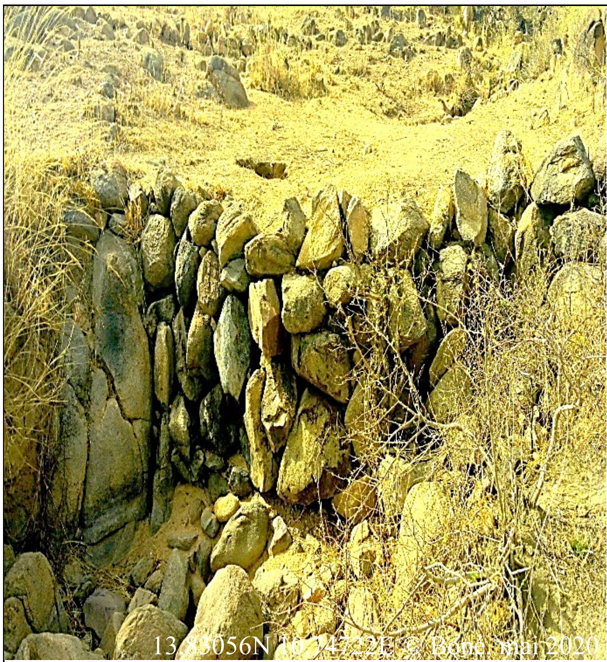
Figure 10 shows the distribution of the various stakeholders involved in the creation of the diversion bays in the Mandara Mountains. There is a marked difference in the involvement and actions carried out between public and private stakeholders, reflecting unequal participation and disparate contributions to the sustainable management of surface water resources.

Good practice in dealing with the degradation of diversion bays in the Collectivities of the Mandara Mountains

Faced with challenges relating to water, the economy and the environment, local authorities and communities, supported by external partners, are implementing innovative solutions aimed at improving access to water and strengthening climate resilience.

Reinforcing infrastructure : a preference for dry-stone diversion bays and concrete diversion bays

Reinforcing diversion bays plays a crucial role in reducing water loss through evaporation and infiltration. Traditional diversion bays, often made of earth or stone using ancient methods, are particularly susceptible to flooding and erosion. Although gabions or masonry provide a degree of stability, they are still vulnerable to rapid deterioration, especially as they require technical expertise to build. To overcome these limitations, local residents are opting to build dry stone or concrete diversion bays, materials that are more resistant to bad weather. These structures enable water to be managed more efficiently, with less loss through infiltration, and are much more durable (Plate 6).



A) Stone mills with à Ksa'a (Mokolo)

B) Concrete reaches at Mandaka (Mokolo)

Photographic plate 6. New approaches to the design of diversion bays in the Commune of Mokolo

This photo shows an innovative approach to the design of diversion bays, using callused stones and concrete. This system effectively captures water from the mayos, preventing it from evaporating or escaping, thereby promoting sustainable management of water resources. It supports irrigation of farmland while preserving riverbanks and fields, reducing dependence on external sources and helping to improve agricultural yields.

Integrating the diversion bays into agro-ecological and promoting water-efficient farming practices

Local organizations are integrating the diversion bays into an approach that combines agriculture and ecology. This adoption of agro-ecological practices, such as agroforestry, hedgerows, and cover crops, not only enhances the functions of the diversion bays but also their maintenance. This model helps to reduce erosion, manage water more efficiently, and regenerate income by growing trees with high economic value, such as mango, guava, lemon and papaya trees, as well as market garden crops (Photo 1).

Photo 1. Agricultural use of the reach water at Mandaka, Commune of Mokolo

This sustainable agricultural approach, adopted by farmers, optimizes yields while preserving the hydraulic system and aquatic biodiversity. It represents a successful synergy between agro-ecology and diversion bay management, promoting responsible management of water resources.

According to the results of a survey of market gardeners, the application of agro-ecological practices leads to a 65% improvement in agricultural productivity compared with land not using these techniques.

Installation of rainwater harvesting and storage systems

The integration of good practices, such as rainwater harvesting systems and irrigation methods that optimize water use, is becoming increasingly common in the *Collectivités des Monts Mandara.* Table V shows the different systems implemented in the communal areas.

Tableau III. Innovative rainwater harvesting and irrigation systems and techniques in the study areas

Commune	Somelocalities	Rainwater harvesting system	Water-saving irrigation technique	Proportion (%)
Koza Mokolo	Mandaka Dourvaya Dzah Djingliya	Underground reservoir	Dripping Irrigation	36,8
Koza Mokolo Bourha Souledé-Roua Mogodé Mozogo	All study areas	Green roofs	Micro-irrigation	91,4
Koza Mokolo Mozogo	Mawa Sodécoton Guétalé Dourvaya Mokola Mandaka Woudahaï Zamalva Mozogo-centre	Collection tanks	Controlled sprinkler irrigation	61,3
Koza Mokolo Souledé-Roua	Djingliya Gouzda Goraï Mandaka Midré	Retention basin	Capillary irrigation	89,7
0	0	Filtration system	Underground Irrigation	0
0	0	Rain garden	Porous pipe irrigation	0

Source: Field surveys, 2024

This matrix provides a summary of the innovative rainwater harvesting systems and water-saving irrigation methods used in the various localities studied. The data reveals a diversity of techniques adapted to local realities. For example, 36.8% of respondents use underground tanks combined with drip irrigation, while green roofs and micro-irrigation, which are more common, account for

91.4%. Water harvesting tanks and controlled sprinkler irrigation are used by 61.3% of people, and retention basins combined with capillary irrigation are used by 89.7%. Some methods, such as underground irrigation or porous pipe irrigation, are still not widely used.

Agricultural practices that encourage efficient use of water, such as drip irrigation, greatly reduce the pressure on waterways while generating substantial savings in household water consumption (Plate 7).

A) Vauxhall rain pockets in Mandaka

B) Calabash systems in Hosséré (Boulangérie)

Photographic plate 7. Intelligent water collection systems, Commune of Mokolo

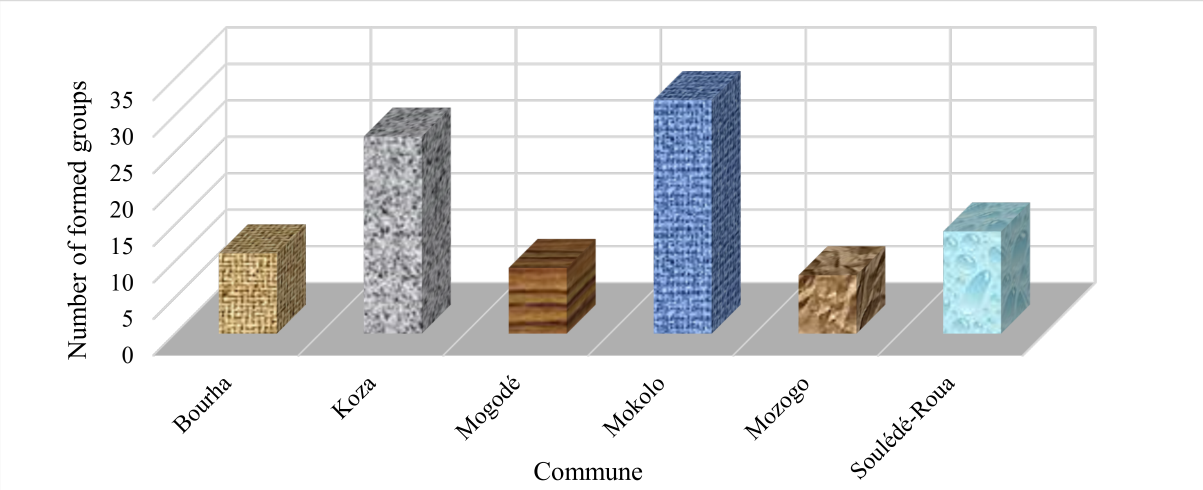
Photo 7 illustrates the ingenious methods used by the inhabitants of the Mandara Mountains to collect water, a striking example of resilience in the face of climate challenges. By making the most of local resources and relying on natural cycles, these systems enable water to be captured and stored efficiently, guaranteeing a sustainable supply for agricultural and domestic needs.

Stakeholder coordination and capacity building

The partnership between local organizations, NGOs, development partners and local authorities plays a key role in the sustainable management of the diversion bays in the Mandara Mountains, integrating the social, economic and environmental dimensions. This model encourages the active participation of local communities, strengthening cooperation between endogenous and exogenous players. Participatory water infrastructure maintenance programs have been set up in areas such as Mandaka, Mayo-Sanganaré, Zamalva (Commune of Mokolo), Djingliya, Hirché, Mandousa, Moutsikar (Commune of Koza), Midré, Bao, Golibaï (Commune of Soulédé-Roua) and Sir (Commune of Mogodé), with the involvement of Management Committees (COGES).

This approach reduces the cost of repairing the diversion bays by 42% and extends their lifespan by an average of 8.5 years. Collaboration between local authorities, NGOs, technical services and private players makes it possible to mobilize resources for large-scale projects, while raising awareness of sustainable water management and infrastructure maintenance. This partnership provides training and awareness-raising for local organizations, which are now involved in preserving water resources (Figure 11).

Figure 7. Distribution of local organizations formed in 2024 for sustainable water management, by Commune



Source: Field surveys, 2024.

This figure highlights the increased commitment of Local Authorities to water management issues, a crucial aspect in the face of the challenges of climate change and dwindling water resources.

In 2024, various local organizations are receiving support in the communes studied, although their number varies considerably from one area to another. The Commune of Mokolo stands out, with 32 organizations, illustrating a significant degree of mobilization and awareness of water-related issues. In contrast, the Commune of Mozogo, with just 8 organizations, faces obstacles in terms of awareness and resources to develop similar projects.

DISCUSSION

The results of this study highlight the challenges associated with the management of water infrastructure in the Communes of the Mandara Mountains, in particular the diversion bays, and underline the persistent difficulties of access to water for local populations. Despite the diversity of supply sources developed since the first development policies in 1974, these efforts remain insufficient. These observations are in line with the work of Hallaire (1991), who already noted the difficulty of access to surface water and underground resources in this region. Although the rainy season provides a temporarily adequate supply, problems multiply at the end of this period and become critical as the dry season progresses. In addition, the gradual decrease in rainfall and the depletion of groundwater resources further aggravate the situation, creating a major water supply challenge in North Cameroon (MIDIMA, 2016; Yemata et al., 2011).Since the 1960s, the inhabitants of the Mandara Mountains have been confronted with this problem. Olivry and Hoorelbecke (1975) had already highlighted the introduction of new water points such as masonry wells built by the Rural Engineering Department in 1968-1969, and boreholes installed in the plains and foothills, which often failed and did not meet the needs of the local population. Recent reports from the Communes' Hygiene and Sanitation Departments (2024) confirm the presence of various water infrastructures, in particular mini-water supply systems, boreholes and wells, both improved and unimproved. However, these facilities are still largely insufficient to meet the needs of the communities. Boreholes, perceived as the most reliable source of drinking water, are preferred by the majority of households, as Sanou Sobze et al (2016) and Tekam Dorine Djuissi et al (2017) have also shown. However, the most disadvantaged households continue to suffer from limited access to quality drinking water.

The conclusions of this study are in line with those of Damien (1992), who emphasized the importance of hill dams in the Mandara Mountains. These micro-dams and ponds, although temporary due to evaporation and lack of renewal, facilitate access to water and livestock watering. Local techniques, such as cross dikes on mayos and small dams built by local people, also make it possible to retain surface water for later uses such as irrigation and watering. Although precarious, according to Pages, Evina, Tchotsoua and Moundji (1999), these practices are proving to be profitable and effective in maintaining water availability in mountainous areas.

However, once built, water infrastructure frequently encounters management problems. Analyses and maps of the diversion bays in the localities studied reveal a significant proportion of degraded structures. This critical situation is confirmed by the CAPROD-CAM report (2020), which highlights the alarming state of many damaged diversion bays. This underlines the key role of local people and town councils in the management and sustainable protection of these structures, as Olivier et al (2000) also point out. The aim is not just to build infrastructure, but also to maintain and perpetuate it.

The causes of the deterioration of the diversion bays are both natural and man-made. Damien (1992) identifies flooding, which has become more frequent, violent and unpredictable, as a major factor in destruction. These floods particularly damage water retention structures, which block the natural passage of water and exacerbate the damage. In addition, the work of Roose (2000) highlights the impact of climatic variations, characterized by considerable irregularity, on the gradual deterioration of the diversion bays.

Human impact plays a central role in the deterioration and survival of hydraulic structures, particularly diversion bays. This observation is in line with Dulawan's research (1985), which highlights the lack of autonomous and responsible management as a key factor in failure. The lack of responsibility on the part of local communities and the inadequacy of financial resources for the management and preservation of these infrastructures are major causes of their degradation, as Charnaux and Werckmann (1990) also point out. In addition, the abandonment of responsibilities by the institutions in charge of managing rural water resources, such as MINADER's *Génie* Rural, GOIB and MIDIMA, exacerbates the situation.

The work of *Gisèle* (2016 and Kissi et al. (2015) corroborates these findings by describing various mechanisms of diversion bay degradation. These include internal and external erosion, as well as biological degradation caused by the proliferation of certain plant species, which contribute to the deterioration of hydraulic infrastructure. This deterioration of the diversion bays has considerable environmental and socio-economic impacts. Ecologically, it leads to the loss of wetlands and disturbances that threaten aquatic biodiversity, as Leveque (2005) pointed out. In functional terms, Cremona (2003) points out that damaged diversion bays can no longer fulfil their role effectively. In addition, siltation problems reduce water retention capacity and compromise water resource management. Finally, the diversity of the players involved in building the diversion bays, with their varying approaches to design and water supply, reflects heterogeneous strategies. These differences, while they may enrich the solutions, also complicate the implementation of harmonized and sustainable management of water infrastructure.

Improving living conditions and managing water infrastructure in the Mandara Mountains relies on active collaboration between various public and private players, both local and external. The State, through MINADER's Rural Engineering Department, plays a central role by offering technologies adapted to the needs of local authorities, including the Communes and the local population. Private organizations such as WWF, Care International and MIDIMA, as well as religious institutions such as the UEBC and the CDD, are also involved in implementing spatial planning policies. However, an analysis of the results reveals some notable shortcomings : the Communes are finding it difficult to mobilize funding to support the monitoring and evaluation mechanisms, while some NGOs, having built the infrastructure, delegate its maintenance to the local people. The latter, for their part, sometimes tend to abandon these structures, exacerbating the situation.

This observation reflects a similar dynamic observed in other regions of sub-Saharan Africa since the 1970s. In countries such as Senegal, Mali, Burkina Faso, Côte d'Ivoire, Mauritania and Chad, public authorities have worked with civil society organizations to develop water infrastructure such as wells, boreholes, standpipes and diversion bays (Ali Blali, 2011).

Faced with global climate degradation and increased erosion, it is becoming urgent to implement initiatives to protect water and soil resources, particularly in rural and mountainous areas where climatic conditions are arid or semi-arid. The construction of micro surface water reservoirs is increasingly integrated into the programs of international organizations, governments and local authorities. In the Mandara Mountains, with the support of external partners, local populations are adopting improved practices for Integrated Water Resources Management (IWRM), which is helping to improve access to water and increase their resilience in the face of water-related challenges. This approach requires close coordination between all local stakeholders.

International initiatives such as the Stampriet Trans-boundary Aquifer System (STAS) and the Senegal-Mauritania Trans-boundary Aquifer System (SASM) are significant examples of this. In 2021, these projects highlighted the importance of international and local cooperation in the sustainable management of water resources. Through the monitoring and sharing of hydrological data, these initiatives aim to preserve aquifers while fostering essential regional collaboration for countries such as The Gambia, Guinea-Bissau, Mauritania and Senegal. These projects, supported by regional organizations such as OMVG and OMVS, demonstrate the effectiveness of the transnational approach (GFA Terra Systems, 2004; FAO, 2001).

In the same spirit, the *Programme d'Appui au Développement des Monts Mandara* (PADM) has launched initiatives to integrate IWRM in the region, with the aim of restoring the reaches and improving access to water for irrigation and human consumption. These efforts, based on cooperation and multi-dimensional approaches, are having a tangible impact on the living conditions of residents and the environmental health of the region.

CONCLUSION

The Mandara Mountains have a rich hydrographic network offering local authorities opportunities to create mini-water reservoirs, such as diversion bays, to meet the needs of rural populations. Made of earth, stone, gabion or concrete, the diversion bays are clean surface water retention structures that are well suited to the needs of local populations. They capture run-off water, store significant volumes of water, supply wells, water livestock and limit erosion. These schemes are a response to the challenges of drought and increasing demographic growth. However, despite their proven effectiveness, these infrastructures are suffering from increasing deterioration, exacerbated by ineffective management, a lack of local involvement, and insufficient financial resources. This situation exacerbates the inadequacy of existing water infrastructures, hampering local development and revealing the limits of regional planning policies in terms of access to water. To ensure a sustainable future, it is imperative to further strengthen good hydraulic and agricultural practices for the sustainable management of water and agricultural resources. This means strengthening and coordinating the players involved, increasing the participation of local populations and adopting innovative solutions. These combined efforts are helping to improve living conditions and stimulate socio-economic development in the Mandara Mountains.

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